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6. AUTHOR(S)
M. YOKOTA, W.J. THARION, M.J. BULLER, AND R.W. HOYT

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army Research Institute of Environmental Medicine
Kansas Street
Natick, MA 01760-50076

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13. ABSTRACT *(Maximum 200 words)*
The Physiological Strain Index (PSI) is a scale for measuring physiological strain in spontaneous response to work and heat stress using heart rate and core temperature. Previous PSI studies were conducted in controlled laboratory conditions. The purpose of this study was to examine if PSI patterns were different during field activities. In addition, whether intensities of activities, times of activities, types of movements in same activities, and environmental stress affect PSI levels were investigated. Twelve male volunteers participating in U.S. Marine Corps infantry training at Quantico, VA, were studied. The PSI was calculated from measured heart rates and core temperatures during field activities. Five activities including firing, attack, preparation, meeting, moving were used in this study. These activities were further classified as "day" or "night" according to the times the activities occurred. Types of movement in attacks and moving activities were categorized as either "mechanized" or "non-mechanized," depending on whether vehicles were used. The Environmental Stress Index (ESI), which summarizes the influence of air temperature, solar radiation, and relative humidity, was also calculated for the field conditions. Fisher's exact tests were conducted to examine if the PSI levels varied for activities, times of activities, types of movements, and ESI. The PSI levels were different for various activities. Fighting activities (firing and attack), in particular, attained high PSI levels with greater variability than non-fighting activities ($p < 0.05$). PSI levels were high during nighttime as compared to daytime fighting activities ($p < 0.05$). PSI levels in mechanized activities were not statistically different from those in non-mechanized activities ($p > 0.05$). High ESI levels were associated with low PSI levels, and vice versa ($p < 0.05$). Although the PSI was different for each activity, the difference in the PSI appeared to correspond to time, particularly when work intensities increased. However, the inverse ESI relationship to the PSI level was unexpected. This suggested that more physically demanding tasks were scheduled at night when ESI levels were low, and vice versa. Further PSI studies with larger sample sizes and more diverse activities are warranted.

14. SUBJECT TERMS
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APPLICATION OF THE PHYSIOLOGICAL STRAIN INDEX (PSI) FOR EVALUATION OF SIMULATED MILITARY ACTIVITIES

M. Yokota[1]
W.J. Tharion[2]
M.J. Buller[1]
R.W. Hoyt[3]

[1] GEO-CENTERS, INC.
190 N. Main St.
Natick, MA 01760

[2] Military Nutrition Division

[3] Biophysics and Biomedical Modeling Division

October 2002

U.S. Army Research Institute of Environmental Medicine
Natick, MA 01760-5007

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EXECUTIVE SUMMARY

The Physiological Strain Index (PSI) (24) is a scale for measuring physiological strain in spontaneous response to work and heat stress using heart rate and core temperature. Previous PSI studies were conducted in controlled laboratory conditions. The purpose of this study was to examine if PSI patterns were different during field activities. In addition, whether intensities of activities, times of activities, types of movements in same activities, and environmental stress affect PSI levels were investigated.

Twelve male volunteers (age: 26 ± 4.0 [SD] yr; ht: 181 ± 4 cm; and wt: 80.4 ± 10.5 kg) participating in U.S. Marine Corps (USMC) infantry training at Quantico, VA, were studied. The PSI was calculated from measured heart rates and core temperatures during field activities. Five activities --firing, attack, preparation, meeting, moving-- with at least four participants per activity were used in this study. These activities were further classified as "day" or "night" according to the times the activities occurred. Types of movement in attacks and moving activities were categorized as either "mechanized" or "non-mechanized," depending on whether vehicles were used. The Environmental Stress Index (ESI) (22), which summarizes the influence of air temperature, solar radiation, and relative humidity, was also calculated for the field conditions. Fisher's exact tests were conducted to examine if the PSI levels varied for activities, times of activities, types of movements, and ESI.

The PSI levels were different for various activities. Fighting activities (firing and attack), in particular, attained high PSI levels with greater variability than non-fighting activities ($p < 0.05$). PSI levels were high during nighttime as compared to daytime fighting activities ($p < 0.05$). PSI levels in mechanized activities were not statistically different from those in non-mechanized activities ($p > 0.05$). High ESI levels were associated with low PSI levels, and vice versa ($p < 0.05$). Although the PSI was different for each activity, the difference in the PSI appeared to correspond to time, particularly when work intensities increased. However, the inverse ESI relationship to the PSI level was unexpected. This suggested that more physically demanding tasks were scheduled at night when ESI levels were low, and vice versa. Further PSI studies with larger sample sizes and more diverse activities are warranted.

INTRODUCTION

Predictions of physiological strain are important in determining the physiological endurance of warfighters and in safeguarding them against thermal stressors while performing their mission. Non-heat acclimated individuals, for instance, tend to have poor skin blood flow and low sweating rates, which lead to increased core temperature and heart rate in response to excessive sweat loss under heat stress (9). To prevent acute heat stress of non-heat acclimated soldiers, military strategies such as wearing thermo-regulated protective clothing (12, 19, 26) and supplying adequate water (1) partially compensate and help to avoid critical body temperatures and dehydration. Choosing nighttime for tactics is also effective to avoid rapid heat stress, although it may generate different physiological or mental stressors against circadian rhythms. Furthermore, resting, self-pacing, or moving to shaded areas are physical strategies to reduce heat stress, although few studies have shown the effectiveness of these movements in varied military field activities under heat stress.

Physiological strain in response to heat stress is commonly measured and detected by scales or indices. However, choosing parameters for calculating the physiological strain that agree with spontaneous body responses to heat stress has been difficult (3). Criteria of a single physiological strain parameter such as sweat rate, metabolism, skin temperature, or heart rate do not spontaneously correspond to the physiological responses to heat stress (3). A single measurement such as skin temperature, sweat rate, or metabolism may require additional time to represent heat strain and/or is susceptible to other environmental conditions (e.g., diet, clothing) besides heat stress (3, 9, 24). Heat strain indices using multiple measurements in previous studies tended to be complicated or restricted to limited populations, time, or environmental conditions (12, 13, 18, 25). McArdle et al. (18) and Hubac et al. (15) established their heat strain indices based on sweat rates, although their indices were limited to acclimated populations and specific working conditions, respectively. An index was needed that did not restrict universal application of the concept of physiological strain assessment to different biological or environmental conditions of heat stress in different time periods. Gonzalez (10, 11) demonstrated that the Effective Temperature Index (ET*), which was defined as dry bulb temperature at 50% relative humidity deriving from the heat exchange from skin surface, ambient temperature and vapor pressure, was linearly related to physiological responses to heat stress. Thus, ET* could be useful in judging the degree of heat stress relative to the thermal physiological responses over a wide range of temperature, humidity, clothing, wind, and acclimation.

Moran et al. (24) developed the Physiological Strain Index (PSI) that can be universally applied in real time for calculating the physiological strain response to heat stress based on heart rate and core temperature. They derived the PSI using data collected on 100 healthy male subjects who periodically exercised under hot-dry environmental conditions, and validated their model using laboratory data collected under different heat stress conditions (20). The PSI equation is simple, corresponds well with heart rate and core temperature changes at any given time, provides a

universal physiological strain scale between 0 and 10, and evaluates work/heat strain in different environmental (e.g., heat, humidity), operational (e.g., clothing, work rates), and biological conditions (e.g., age, sex).

Controlling environmental, operational, and biological conditions while collecting sufficient human physiological measurements is difficult in long-term field studies. Thus, evaluations of the PSI in different conditions have typically been conducted in a controlled laboratory (21, 23, 24). This study investigated the association of the PSI with military field activities. The PSI levels were examined by time (day or night), types of movement (mechanized or non-mechanized) in the same activity, and by environmental stress.

MATERIALS AND METHODS

SUBJECTS

Twelve (12) male subjects were recruited from U.S. Marine Corps (USMC) infantry field training at Quantico, VA, September 8-15, 1999. Test volunteers provided informed consent after the study's purpose and procedures were explained.

This PSI study was a part of a Warfighter Physiological Status Monitoring (WPSM) field study to evaluate trainees' overall physiology (core temperature, heart rate, energy intake, and expenditure) based on the different operational (activities) and environmental (geographic locations [GPS], meteorology) conditions during training.

FIELD PROCEDURES

The USMC training involved both physical and mental exercises in tactics, combat, and the use of weapons and communications within a platoon. Subjects wore body armor and battle dress uniforms during the exercises and carried various equipment based on their assignments. Loaded weights were monitored every hour. The subjects reported their hourly activities using activity log books.

DATA COLLECTION

Physiology

Heart Rate and Core Temperature. Heart rate and core temperature of these subjects were monitored every minute, 24 hours a day. Heart rate was monitored using a chest-strap sensor (Vantage XL model, Polar Electro, Ft. Washington, NY). Core temperature was measured by telemetry temperature pills (2.2 cm x 1.0 cm; Human Technologies Inc., St. Petersberg, FL) using a Body Core Temperature Monitor Receiver (Fitsense, Inc., Wellesley, MA).

PSI. The PSI was calculated as follows (24):

$$PSI = 5(T_{core\,t} - T_{core0}) \cdot (39.5 - T_{core0})^{-1} + 5(HR_t - HR_0) \cdot (180 - HR_0)^{-1},$$

where T_{core0} and HR_0 are the initial core temperature and heart rate measurements, and $T_{core\,t}$ and HR_t are simultaneous measurements taken at any time *t*.

The calculated PSI was summarized by averaging 5-minute intervals and classified into categorical scales ("none/little", "low", "moderate", "high", "very high") based on PSI levels from Moran et al. (24) (Table 1).

Table 1. Calculated PSI from 100 subjects' heart rates (HR, beats/min) and core temperatures (T_{re}, $^{\circ}C$) from Moran et al. (24)

Strain	**PSI**	**HR, beats/min**	T_{re}	**N**
	0	71 ±1.0	37.12 ± 0.03	100
No/Little [1]	1	90 ± 1.1	37.15 ± 0.04	47
	2	103 ± 1.1	37.35 ± 0.03	81
Low [2]	3	115 ± 1.3	37.61 ± 0.03	80
	4	125 ± 1.4	37.77 ± 0.04	61
Moderate [3]	5	140 ± 1.9	37.99 ± 0.05	28
	6	145 ± 5.3	38.27 ± 0.07	13
High [4]	7	159 ± 1.3	38.60 ± 0.04	6
	8	175	38.7	1
Very high [5]	9			0
	10			0

[ ] represents numerical labels corresponding to the categorical strain used in this study.
N represents number of subjects.

Environment

The Environmental Stress Index (ESI), developed by Moran et al. (22), was used to characterize different environmental conditions. The ESI summarizes environmental stress as a function of solar radiation, air temperature, and humidity. It corresponds closely to the Wet Bulb Globe Temperature (WBGT), the international standard for heat stress ($R^2 = 0.98$) (22). Unlike WBGT, the parameters of the equation are generally more available. The ESI formula was calculated as:

$$ESI = 0.63T_a - 0.03RH + 0.002SR + 0.0054(T_a \cdot RH) - 0.073(0.1 + SR)^{-1}$$

where T_a, RH, and SR represent air temperature (°C), relative humidity (%), and solar radiation (W/m^2), respectively. Except for solar radiation, the weather information was collected every 15 minutes during the training period by a portable weather station (Model 10, Campbell Scientific, Logan UT). Because solar radiation was not directly measured at Quantico, it was necessary to obtain a reasonable approximation of hourly ambient solar radiation levels for input to the ESI calculation. A database of hourly solar radiation measurements, obtained at Ft. Benning, Georgia, provided multiple-day average profiles of solar radiation levels. The geographic differences in hourly solar radiation profiles for clear weather in early September were considered to be minimal (Matthew, personal communication, 2001). Those data were then used to construct a schedule of hourly solar radiation values (along with the locally measured air temperature and relative humidity) for input, to ESI. Average solar radiation was estimated as 0 W/m^2 during 20:00-6:00 hours; 100 W/m^{2}during 6:00-8:00 hours and 18:00-20:00 hours; 400 W/m^2 during 8:00-10:00 hours and 16:00-18:00 hours; 600 W/m^2 during 10:00-12:00 hours and 14:00-16:00 hours; and 800 W/m^2 during 12:00-14:00 hours. The ESI was classified based on heat categories corresponding to WBGT index (°C) in the Marine Corps field manual (7).

Activity

Hourly reported activities were initially coded by type of activity (e.g. attacks, movements, grenades, eat, sleep), method of movement (e.g. foot movement, mechanized movement, stationary), and level of activity (e.g. high, moderate, low) in the WPSM field study (5). Because the detailed activity codes decrease sample size, and similar activities had similar physiological responses, activity codes were simplified in this study. For example, seven original categories of attacking activities, including regular attack, 240, counter, mechanized, NBC, night, LZ bluejay-mechanized (5), were collapsed into one group. Similarly, 41 original classifications of movements, which were primarily categorized by locations (ambush site, R-11, R-15) and time (day or night), were summarized into one group. Activities in this study were further categorized based on the analyses discussed in the next section.

SAMPLING PROCEDURES AND DATA ANALYSES

Because repetitive activities conducted by a single individual would be bias for investigating PSI patterns, periods were selected when four or more test subjects were participating in a given activity. These periods occurred on September 8, 9, and/or 14. In addition, to evaluate whether the magnitude of subjects' distributed loads, which lacked normality, affects different PSI levels, Kruskal-Wallis test and Levene's test were conducted separately for the means and distributions of load expressed as a percentage of body weight.

Five activities and their PSI levels were examined: firing guns (FIRE), attacking (ATTACK), meeting (MEET), moving to a different location (MOVE), and preparing for the next activity (PREPARE). FIRE and ATTACK were categorized as fighting activities, while MEET, PREPARE, and MOVE were assigned into non-fighting activities. To examine whether the time of an activity affects PSI levels, each activity was classified as "day" (6:00-17:00 EST) or "night" (17:00-6:00 EST) according to the time it occurred.

The PSI levels in ATTACK and MOVE were also examined by methods of the activities. When subjects attacked using vehicles such as riding a tank, then the activity was labeled as "mechanized," otherwise it was classified as "non-mechanized." Similarly, MOVE was categorized as "mechanized" when subjects were moving by vehicles, while "non-mechanized" when they were walking from one place to another.

Due to a lack of normal distribution in the data and decreasing sample sizes when using continuous PSI scales (1-10), the PSI levels and activities were analyzed using Fisher's exact tests. Further analyses of physiological patterns were conducted with Median tests, which perform nonparametric tests on the equality of medians.

RESULTS

SUBJECTS' CHARACTERISTICS

The age, physical characteristics and resting metabolic rates (RMR) for the 12 test volunteers are shown in Table 2.

Table 2. Age and physical characteristics of subject samples

Subjects	Age (yr)	Height (cm)	Nude weight (kg)	Body Fat %	RMR (kcal/d)
1	25	180	75.0	14.9	1748
2	24	186	81.8	17.6	1826
3	23	175	64.9	12.2	1602
4	25	183	102.0	19.1	2152
5	25	186	81.3	13.0	1898
6	28	175	69.4	13.7	1664
7	23	180	80.6	18.8	1783
8	24	178	77.1	15.7	1774
9	23	178	74.6	16.2	1721
10	33	180	87.4	21.6	1850
11	25	183	95.5	18.4	2053
12	27	183	74.6	8.7	1841
Mean	26	181	80.4	15.8	1826
SD	4	4	10.5	3.6	154

RMR = Resting Metabolic Rate = Kcal/d = 370 + 21.6*FFM,
where FFM (Fat Free Mass in kg) = nude wt – [nude wt x % body fat]) (6).

LOADED WEIGHTS

The grand mean load carriage in this study was 46.1 $\pm$ 8.5 kg. However, because individuals with different body weight carried various loads based on their job assignments, the percentage of loaded weight relative to body weight (PERLDWT = [loaded weight / body weight] *100) was calculated to examine the PERLDWT effects on the PSI levels. Table 3 shows a distribution summary of PERLDWT including clothing weights based on available PSI levels. For instance, 14 and 53 PSI observations were found in subject #9, while carrying approximately 30%-40% and 60%-70% of his body weight, respectively. None of the subjects carried loads of 40%-50% of their body weight. On average, subjects carried loaded weights equivalent to approximately 58% of their body weights during their assignments. Table 4 shows a descriptive summary of PERLDWT by the PSI levels. Kruskal-Wallis test did not show differences in mean PERLDWT among PSI levels ($p > 0.05$). Levene's test of homogeneity of variance showed the distribution of PERLDWT was homogeneous among PSI levels ($p > 0.05$). Thus, the magnitude of PERLDWT did not affect PSI levels in this study.

Table 3. The distribution of loaded weight including clothing weights relative to body weight

SUBJECT NO.	Load expressed as a % of body weight							
	20-30	30-40	50-60	60-70	70+	Total	Mean (%)	SD (%)
1	0	0	0	111	1	112	63.9	1.3
2	0	0	0	52	0	0	65.4	0.9
3	0	9	0	0	74	83	78.9	16.5
4	0	69	0	0	0	69	38.7	1.4
5	8	0	0	21	0	29	51.4	16.1
6	0	0	9	0	0	9	55.2	0.0
7	0	0	15	0	0	15	58.6	0.0
8	0	0	0	23	0	23	63.6	0.0
9	0	14	0	53	0	67	59.8	12.2
10	6	0	24	61	0	91	56.6	8.7
11	32	0	97	0	0	129	44.0	11.2
12	2	0	0	73	0	75	60.3	6.6
Total	48	92	145	394	75	754	58.0	6.2

Table 4. A descriptive summary of load expressed as a percentage of body weight (PERLDWT) by PSI levels and the results from Kruskal-Wallis and Levene's tests

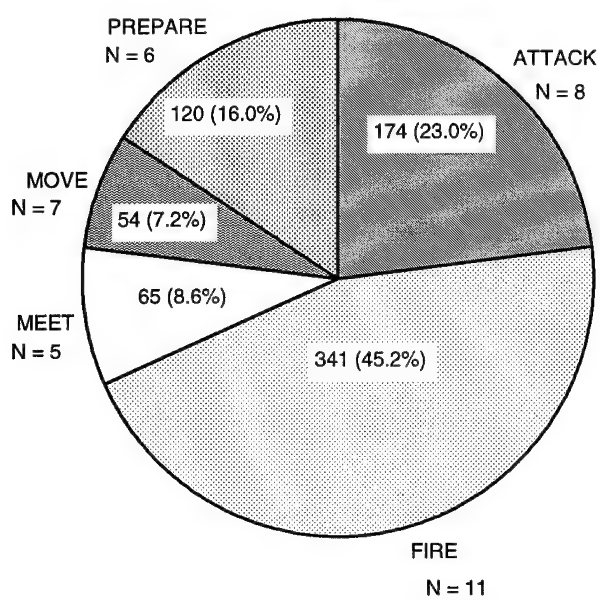
PSI LEVEL	Mean(%)	±SD(%)	Observations
No/little	57.4	14.9	605
Low	58	15.3	98
Moderate	60.7	10.8	44
High	53.4	11.3	6
Total	57.6	14.7	753

Kruskal-Wallis Test $H_{[3]} = 2.908$, $p = 0.41$.
Levene Statistic $(3, 749) = 1.4$, $p = 0.24$.

ACTIVITIES

Figure 1 shows the summary of observed frequencies by activity. For instance, 341 PSI readings observed in 11 subjects were recorded as FIRE activity. In ATTACK activities observed in 8 individuals, 174 PSI readings (23.0% of total PSI readings) were available. Five subjects reported MEET activities, which consisted of 65 PSI counts.

Figure 1. Summary of observed PSI frequencies by activity



METEOROLOGY

Table 5 summarizes meteorological data for the test days (September 8, 9, and 14). The heat stress associated with environmental factors is different by hours: As expected, daytime air temperature was higher than nighttime air temperature, while nighttime relative humidity was much higher than daytime relative humidity. Because the lower two heat categories of the WBGT index (7) correspond to the ESI values used in this study, the ESI was categorized as "high" when the value was greater than 25, or "low" when less than 25.

Table 5. Descriptive summary of meteorological data

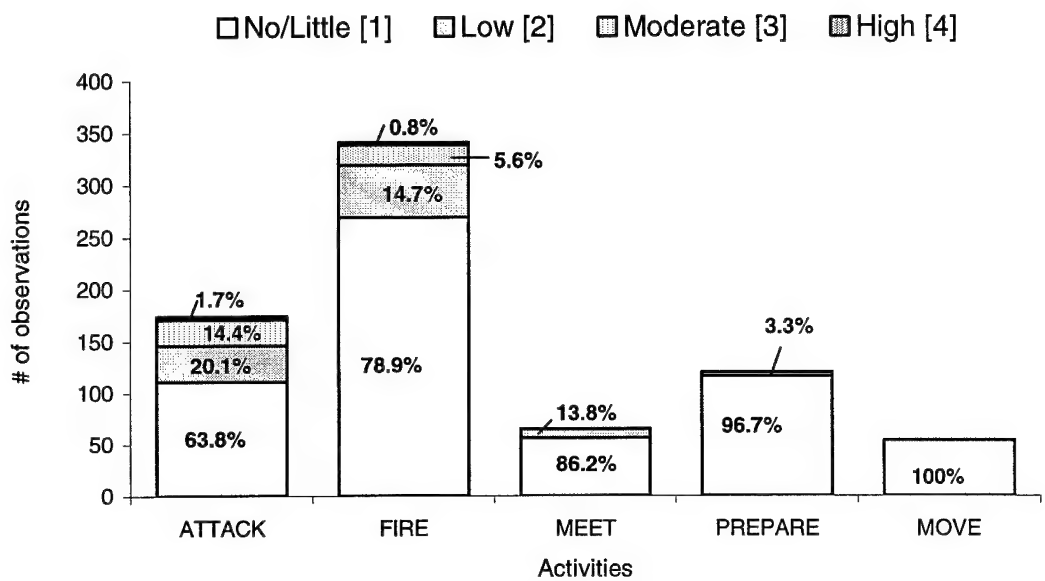
	ESI (°C)	Ta (°C)	RH (%)	Estimated SR (W/m^2)
Hours	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
6:00-17:00	25.1 ± 1.6	27.2 ± 3.1	69 ±17	467.8 ± 211.3
17:00-6:00	21.1 ± 1.4	21.2 ± 1.4	95 ± 5	98.7 ± 127.4
Grand Summary	23.1 ± 2.5	24.2 ± 3.8	82 ±18	281.3 ± 253.7

ESI = Environmental Stress Index
Ta = Air temperature
RH = Relative humidity
SR = Solar radiation

PSI SUMMARY BY ACTIVITIES

Figure 2 shows the PSI readings by activities. Greater variability of PSI scores ranging from "No/Little" to "High" was observed in fighting activities (FIRE and ATTACK). Low PSI scores were consistently shown in non-fighting activities (MEET, MOVE, PREPARE). This result yields higher PSI mean and standard deviations (SD) in fighting activities than in non-fighting activities. PSI means and SD in ATTACK and FIRE, which were calculated from the scores of strain categories shown in brackets, were 1.54 $\pm$ 0.8 and 1.3 $\pm$ 0.8, respectively. PSI means and SD in MEET and PREPARE were 1.1 $\pm$ 0.4 and 1.0 $\pm$ 0.2, and MOVE, in which only "No/Little" PSI was observed, scored 1.0.

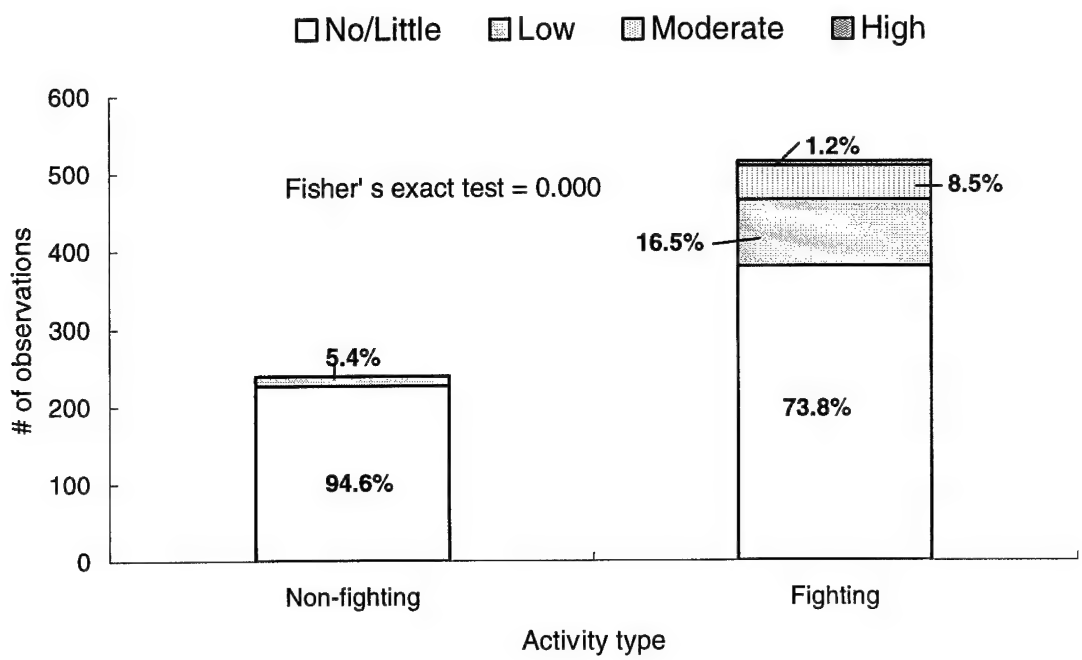
Figure 2. Frequencies and descriptive summaries of the PSI level by activities



[] represents numerical labels corresponding to categorical strain.

Comparisons of the PSI levels between fighting and non-fighting activities based on the Fisher's exact test are summarized in Figure 3. The higher PSI levels are more likely to be observed in fighting activities than non-fighting activities ($p < 0.05$).

Figure 3. Physiological Strain Index (PSI) values for fighting and non-fighting activities



Figures 4 and 5 are median summaries of the heart rate and core temperatures for fighting and non-fighting activities, respectively. The median test shows that the heart rate in fighting activities was higher (94.4 ± 20.2[SD]) than that measured in non-fighting activities (90.0 ±13.2 [SD]). The difference in median core temperatures between fighting and non-fighting activities, although only 0.1°C, was statistically different ($p < 0.05$) due to the large number of observational readings and the heterogeneous datasets.

Figure 4. Median heart rate comparison between fighting and non-fighting activities

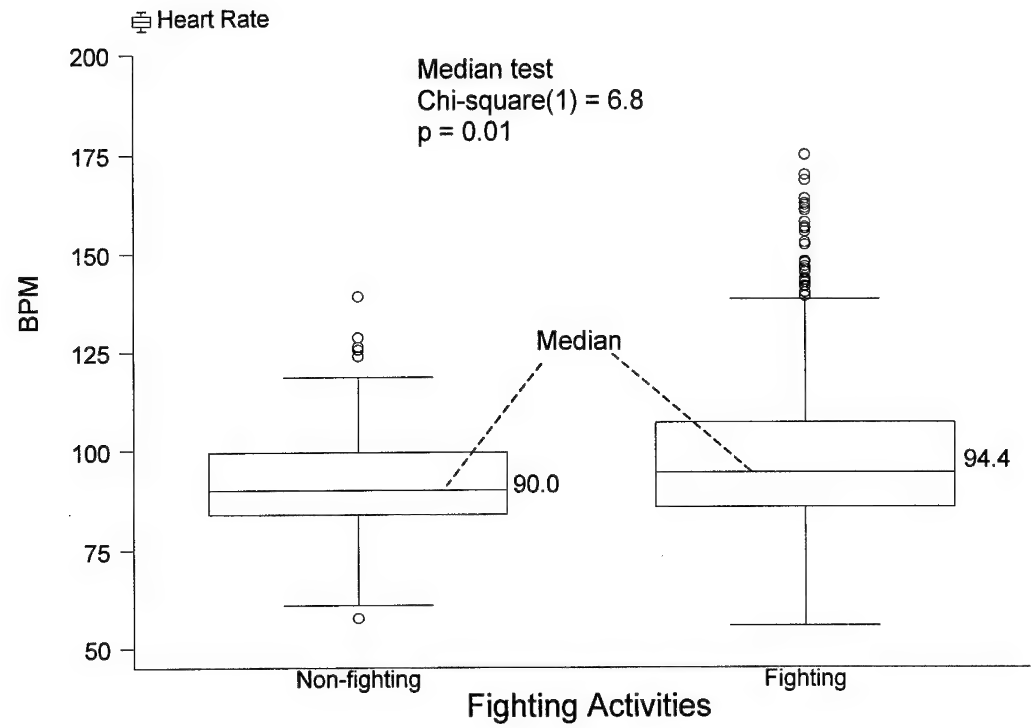
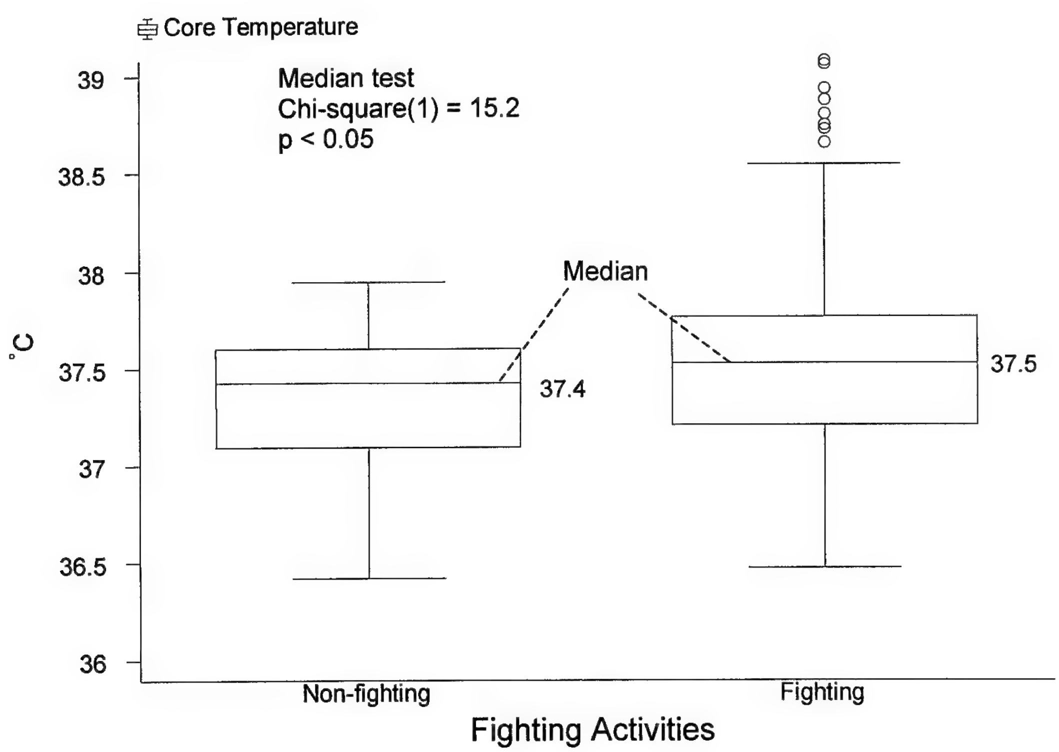


Figure 5. Median core temperature comparison between fighting and non-fighting activities



PSI LEVELS BY TIME IN THE SAME ACTIVITY

Differences in the PSI levels between "night" (17:00–6:00 hours) and "day" (6:00–17:00 hours) were compared by Fisher's exact tests. Because five activities were simultaneously tested, Bonferroni's corrections for multiple comparisons were applied. A significant level of 0.01 was applied to obtain a statistical significant level of p=0.05 (0.01 x 5). PSI distributions of non-fighting activities by hours based on Fisher's exact tests are summarized in Figure 6. Low PSI levels were consistently observed in both night and day. The associations between PSI level and time of activities were not statistically evident (p > 0.01) during non-fighting activities.

Figure 6. Comparisons of the PSI levels for non-fighting activities by time

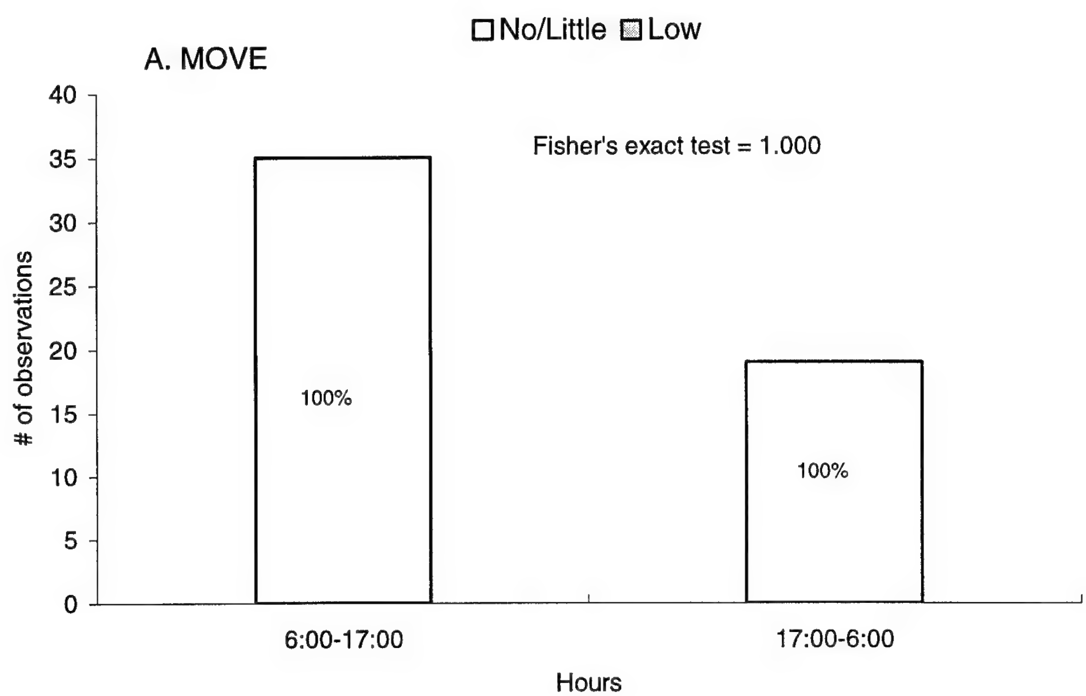
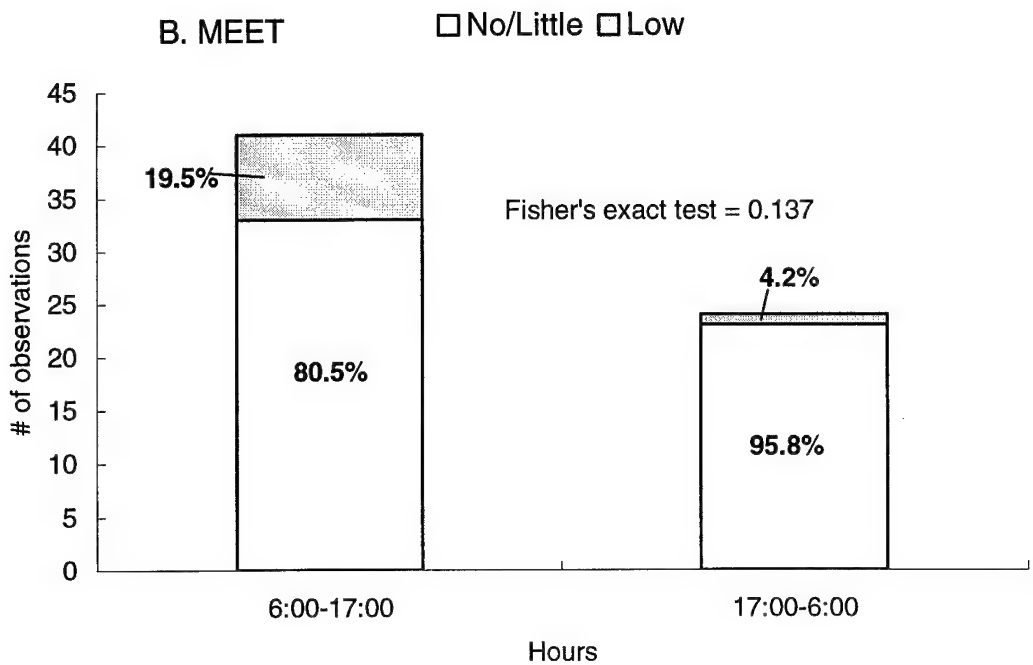
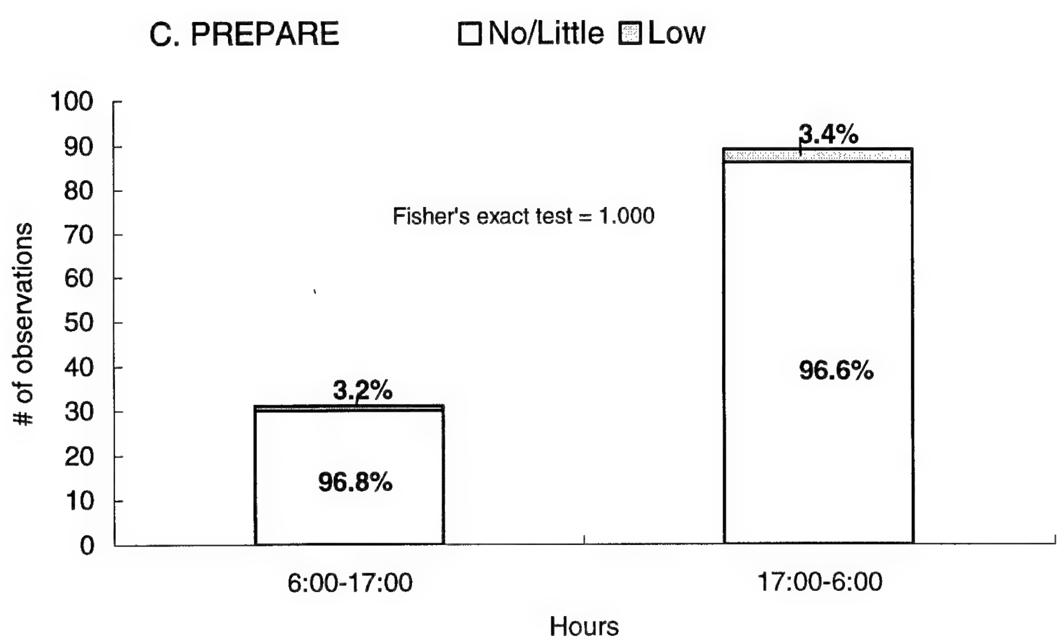


Figure 6 (cont.)

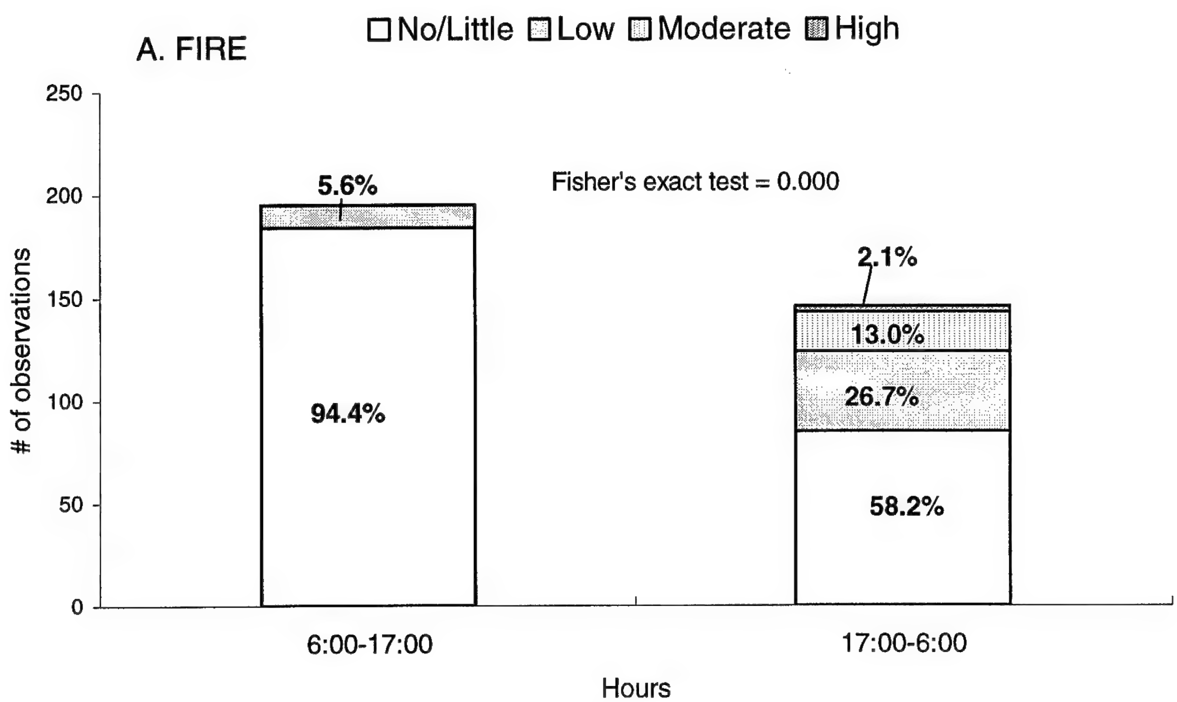




Fisher's exact comparisons of the PSI levels between hours in fighting activities (FIRE, ATTACK) are shown in Figure 7. Nighttime fighting activities scored higher than daytime for PSI ($p < 0.01$).

Figures 8 and 9 are median summaries of heart rate and core temperature during fighting activities by hours, respectively. In both fighting activities, the median heart rate during nighttime compared to daytime was above 100 bpm with greater variability. The median core temperature during the nighttime was increased approximately 0.5°C from the daytime body temperature. Median tests confirm that physiological responses differ by time ($p < 0.01$).

Figure 7. Comparisons of the PSI levels for fighting activities by time



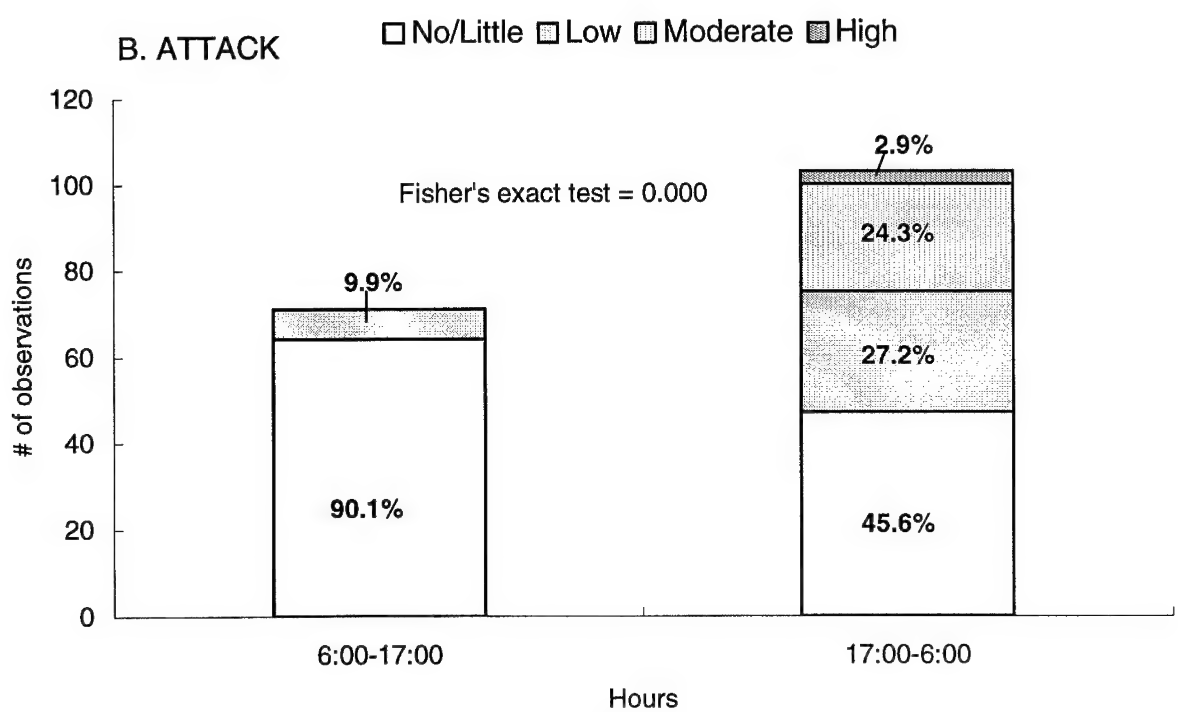


Figure 8. Comparisons of median heart rates for fighting activities by time of day

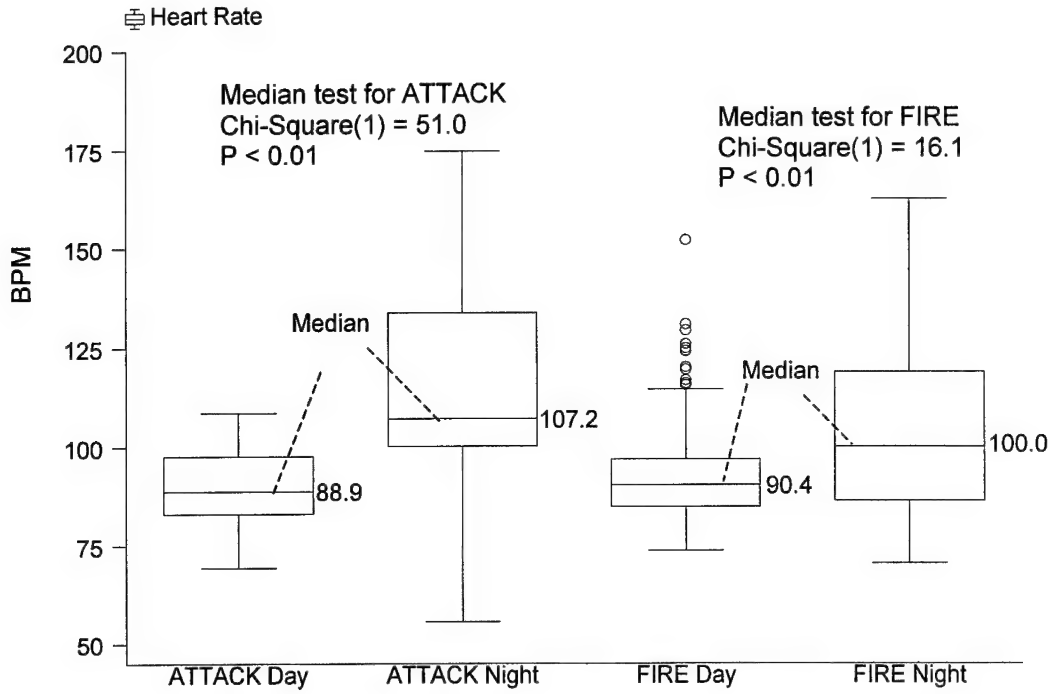
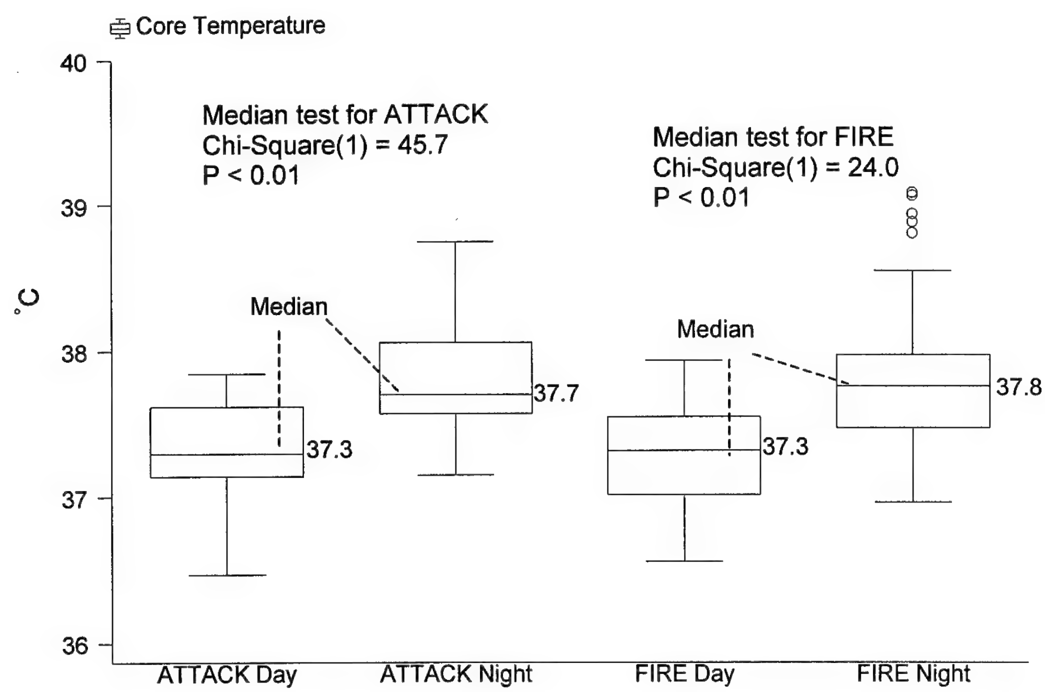


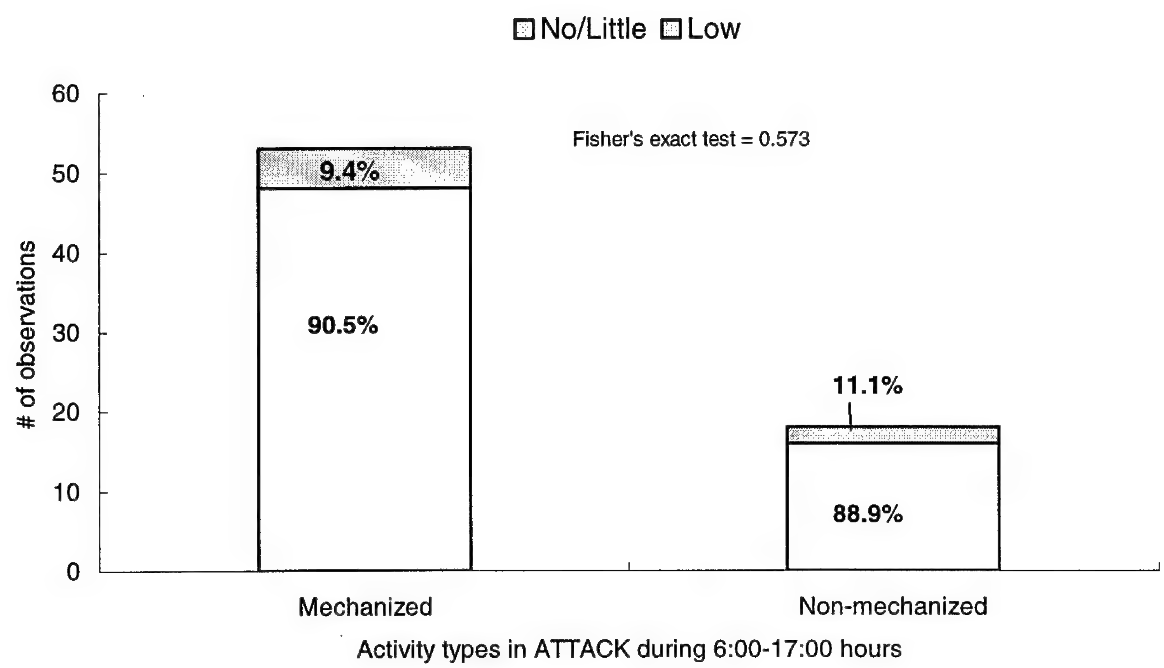
Figure 9. Comparisons of median core temperature for fighting activities by time of day



PSI LEVELS BY METHODS OF MOVEMENT IN THE SAME ACTIVITY

The distributions of the PSI levels between mechanized and non-mechanized activities were separately examined in MOVE and ATTACK using Fisher's exact tests. Due to the consistent "No/Little" PSI level in Figure 6A, the MOVE did not show statistical differences in the PSI levels by the types of movements. Because the PSI levels in ATTACK were affected by time (Figure 7B), the Fisher's exact tests were conducted separately by time of day. Figure 10 shows the comparisons of the PSI level distributions between mechanized and non-mechanized attacks that occurred during daytime. Methods of attacks do not affect PSI levels (p = 0.573). During nighttime, only non-mechanized attacks were observed.

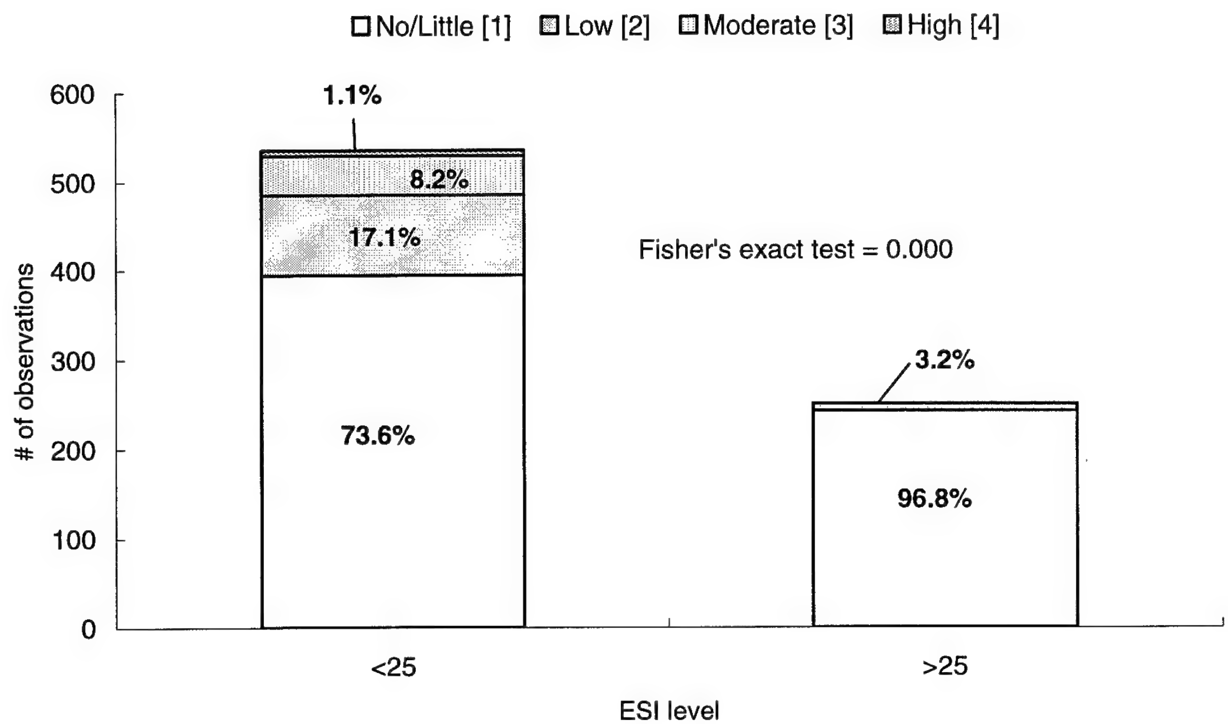
Figure 10. Comparisons of the PSI levels between mechanized and non-mechanized attacks by time



PSI LEVELS ASSOCIATED WITH ESI LEVELS

The associations of ESI with PSI levels are summarized in Figure 11. Low ESI levels were unexpectedly associated with higher PSI levels ($p < 0.05$). Mean PSI during low ESI conditions was 1.34, while mean PSI under high ESI conditions was 1.0. However, this result is biased by the times when activities were assigned during training. Nighttime military activities, which triggered high PSI responses, were scheduled only when ESI was low. High ESI levels were observed only during daytime military activities.

Figure 11. PSI distributions of Fisher's exact tests by ESI category



[] represents numerical labels corresponding to categorical strain.

DISCUSSION

In this study, data collections, sample sizes, and a study design compelled by field conditions caused limited examinations of physiological heat stain using PSI. Test volunteers were randomly assigned with different activities in different time periods, which lead to ambiguity in their activity reports, reduced sample sizes, and decreased powers in statistical analyses. In addition, the elements (weather, load, activity, times, clothing) caused different PSI levels that were difficult to coordinate due to random activity assignments in the field training. Examining load distributions, selecting consistent clothing logs, finding activities conducted by multiple subjects, and using the ESI to assess the overview of environmental conditions were partial efforts to evaluate PSI patterns objectively. Furthermore, missing data and invalid physiological measures were often recorded in this field study, which reduced the number of available PSI values.

However, this study showed the following PSI patterns. First, different physiological strain levels were observed in different activities. Although subjects carried different loads based on their assignments, it did not significantly affect the PSI levels due to the equal distributions of loads between PSI categories. Fighting activities (FIRE, ATTACK) scored approximately 1.4 times higher PSI levels with greater variances than non-fighting activities (MEET, PREPARE, MOVE). However, when PSI levels were compared by time between fighting and non-fighting activities, physiological strains during daytime fighting activities were as low as those during daytime non-fighting activities. Because fighting activities that occurred during the nighttime attained approximately 1.7 times higher PSI levels than the same activities during the daytime, high physical strains in this study were primarily associated with the time of fighting activities.

Daytime PSI levels of armored vehicle attacks were not statistically different from daytime PSI levels with physical assault. This result indicates that stress levels did not differentiate within the sequence of daytime attacks when vehicle attacks were conducted prior to physical attacks.

Physically demanding activities reflected cardiovascular and thermal strains. As corresponding to PSI levels, median heart rate and core temperatures were greatly increased by time of assaulting activities. Median heart rates of pooled fighting activities during nighttime were approximately 103.9 ± 24.1 [SD] bpm, which is approximately 15 bpm higher than the same activities conducted during daytime (89.0 ± 11.7 [SD]). Similarly, median core temperatures in pooled nighttime fighting activities (37.7°C) were approximately 0.4°C higher than that in daytime fighting activities (37.3°C). Heart rates above 160 bpm, which correspond to extremely demanding physical work (16), were observed in 51 readings among 6 individuals during nighttime fighting activities, but only 1 individual was observed over 160 bpm in daytime non-fighting activities. Core temperatures above 38.5°C, the threshold for heat exhaustion (14), were recorded in 55 readings among 5 individuals during nighttime fighting activities,

but only 1 individual was observed in daytime non-fighting activities. These stronger physiological responses at night may be due, in part, to non-acclimated responses to the time of the stressful activities and nighttime conditions requiring increased mental alertness and anxiety (2, 4, 8, 17).

The ESI range was not diverse enough to influence physiological strain in this study. Daytime average ESI (25.1 ± 1.6) was slightly higher than nighttime ESI (21.1 ± 1.4). ESI frequencies were significantly ($p < 0.05$) but unexpectedly inversely associated with PSI categories. High ESIs (≥ 25) were recorded only when PSIs were low, while low ESIs (<25) were observed in both high and low PSI activities. Such results were due to the times activities were assigned during the training. High ESI levels were observed only during daytime activities, and nighttime fighting activities, which increased PSI levels, were scheduled when environmental stress was lower. Thus, high strains caused in this study were due to work intensities and time of work, rather than environmental stressors.

In conclusion, military field simulations are essential not only to test whether prediction parameters are valid for real operations but also to document response characteristics resulting from combinations of different climates, activities, and times during the trainings. The PSI equation used in this study was useful to detect stressors of different military tasks. Unlike previous laboratory-controlled validation studies, this study demonstrated that high PSI levels were particularly associated with times of assaulting activities, even under mild environmental heat stress. However, based on limitations of this study, the following are recommendations for improving PSI studies: First, assigning all subjects to conduct periodical field activities that are controlled for consistent operational and environmental conditions would help to focus on details of PSI patterns, clarify the activity patterns, as well as increase sample sizes and statistical powers for analyses. Second, various military assignments besides activities used in this study may be scheduled to examine the associations between the training and its stress response. Lastly, studying whether soldiers are able to acclimate their physiological strain responses during night attacks by repeated trainings may be important to further examine characteristics of PSI.

CONCLUSIONS

The Physiological Strain Index (PSI) was designed to express spontaneous physiological strain responses to heat stress in a simple equation based on heart rate and core temperature. The index was validated in previous studies under heat strained laboratory conditions. This study examined PSI responses in different activities during the field training. Although the environmental stress was mild during the field exercise, the following PSI characteristics were observed. First, PSI responses were different by activities. Assaulting activities, which were expected to be high physical strains, attained high PSI levels with increased variability, while non-assaulting activities scored low PSI levels. These high PSI levels were particularly observed when soldiers were engaged in nighttime assaulting activities, suggesting that potential mental alertness was required during these activities, besides physiological responses to work intensities. The associations between the PSI and environmental stressors were inconclusive in this study, due to lack of variations in environmental stressors and activity scheduling based on the training course. Because field operations tend to limit conditions such as data collections, activity schedules, and weather, careful planning to resolve such limitations is important for future PSI field study.

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